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VI.

Pritchard's Wedge Photometer.

By S. P. LANGLEY, C. A. YOUNG, and E. C. PICKERING.

Presented November 10, 1886.

The attention of astronomers has been directed to the use of a wedge of shade glass as a photometer by the publication of the Uranometria Oxoniensis. The excellent measures contained in this work of the light of the stars were made with an instrument devised by Professor Charles Pritchard. A sliding wedge of shade glass was inserted between the eye of the observer and the eye lens of a telescope. The star to be measured was brought into the field of view, and the wedge moved until the star disappeared. A graduated scale attached to the wedge served to measure its position, and consequently the thickness of glass required to render the star invisible. In order that I might submit an instrument of this kind to a careful test, I requested Professor Pritchard to order the construction for the Observatory of Harvard College of a photometer like his, which he kindly consented to do. On receiving the instrument, it seemed best to subject it to an examination at various observatories. The neutral color of the glass is of course a matter of prime importance. To the eye this particular wedge is all that can be desired, and probably the errors from this source would not affect ordinary star measurements. A severer test is, however, required to detect small systematic errors, especially in the case of colored stars. For this purpose it is necessary to determine the absorption of each portion of the wedge for rays of various wave-lengths. The bolometer appears to be the best instrument for this purpose, and Professor Langley agreed to make the required measurements, the result of which is given below.

To determine how far the instrument is to be recommended to those undertaking photometric observations, it was desirable that it should be tried by some one skilled in the use of astronomical and physical instruments. It was also preferable that the observations should be made by some one who had not acquired special skill with any one form of stellar photometer, and thus become prejudiced in its favor. These conditions are fulfilled by Professor Young, who fortunately was willing to undertake the required examination, and who has kindly prepared the statement given below.

Some Photometric Observations with the Pritchard Wedge.

BY C. A. YOUNG.

At the request of Professor Pickering, I have made a few observations with the Pritchard wedge photometer belonging to the Harvard College Observatory. I regret that unfavorable weather and other circumstances have prevented the series from being more complete. The instrument has the wedge next the eye. The eye-piece, which magnifies the star image, is a *single lens*, in the focus of which is a small diaphragm. The lowest power lens of the three provided with the instrument was always used, and the $\frac{1}{4}$-inch diaphragm. With the 23-inch telescope the magnifying power was about 300, and the field of view was about $2\frac{1}{2}'$, far too small for convenience. Great difficulty was found in keeping the eye so placed as to receive the emergent pencil, as the long, flat surface of the metal plate that protects the wedge was in the way of the nose and forehead. If the wedge, instead of being next the eye, were placed at the principal focus of the eye-piece, where micrometers are usually put, it would be much easier to use the instrument; nor do I believe that, with proper precautions, there would be any loss of accuracy. There should be also some device for automatically recording the readings without the necessity of using a light. Being without an assistant available for the purpose, I had to make and record my own readings, and, after making a reading and recording it, it was necessary to wait a considerable time until the eye had regained its sensitiveness before making a new reading. By taking the precaution to make the extinctions always with one eye (the left), and to keep that eye closed while making the reading and record with the other eye, I found it possible to reduce this waiting period somewhat, and to make and record the extinctions at the rate of about two in five minutes.

The observation of extinctions was found very trying to the eyesight, — the intent gazing into absolute darkness after a luminous point that was almost invisible, or visible only by intermittent glimpses, and the gradual pushing of the wedge until one was sure that the star at last just could *not* be seen. On two out of the four evenings the work was stopped at the end of about two hours by an attack of transient *hemiopsia*. However it may be in respect to accuracy, it is unquestionable that the observation of *extinctions* is much more wearisome and difficult than that of *equalizations*, as in the various forms of double-image photometers.

The observations were made upon six stars in the A. A. A. S. star magnitude

chart of the region following γ Pegasi. They are designated by corresponding numbers in Fig. 1. On the original chart their magnitudes were given as follows, viz.: No. 1, 10th; No. 2, 11th; No. 3, 11th; No. 4, 11th; No. 5, 11th; and No. 6, 13th. Of course these magnitudes, shown by the symbols on the chart, are only intended to be roughly accurate, no gradations smaller than whole magnitudes being indicated. The points surrounded by dotted circles indicate stars not contained in the original chart, but added by the Princeton telescope. The observa-

REGION FOLLOWING γ PEGASI. PHOTOMETER STARS. OCTOBER, NOVEMBER, 1886.

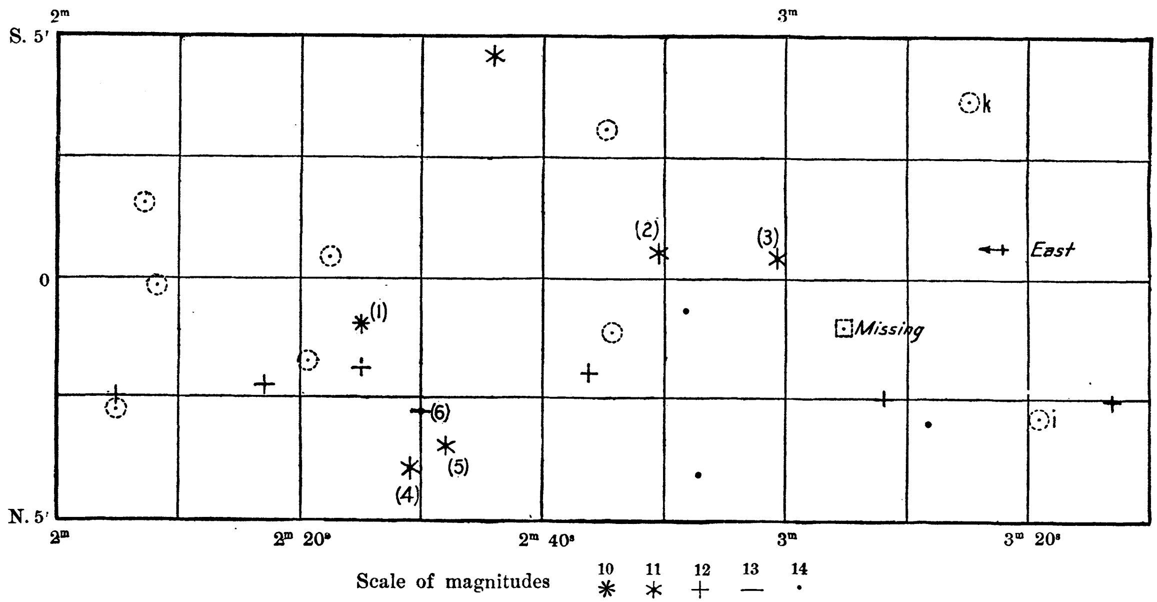

FIG. 1.

tions were made in the following order. First, five extinctions of Nos. 1, 2, and 3, then five each of 3, 2, and 1, in reverse order; the whole thirty extinctions taking about an hour and a quarter. Then five extinctions each were made of the smaller stars, 4, 5, and 6. On the first night, however, only No. 5 was observed.

In reducing the observations, the mean of the thirty readings of the first three stars was taken, and the mean of all the readings of each of the stars was compared with this mean. In the table below, Δ_1, Δ_2, etc. are the differences between the extinction points for each star and the mean of Nos. 1, 2, and 3; the columns headed *r* are the differences between the individual results and the mean result for the four evenings. A plus sign in the Δ column denotes that the star was *brighter* than

the mean of the 3, which mean was used as the standard. The observations were all made within $1\frac{1}{2}$ hours of the meridian. November 4th was bright moonlight. There was a slight moonlight during part of the observations of November 1st, but not enough to be troublesome; the background on which the stars disappeared became perfectly black before they vanished, which was not the case on November 4th with stars 4 and 6. These were lost to the eye, while the sky background was still visible in the diaphragm hole.

	10 Readings.		10 Readings.		10 Readings.		5 Readings.		5 Readings.		5 Readings.	
	Δ_1	r_1	Δ_2	r_2	Δ_3	r_3	Δ_4	r_4	Δ_5	r_5	Δ_6	r_6
	in.		in.		in.		in.		in.		in.	
Oct. 21	+0.410	+.001	−0.373	−.100	−0.038	−.105	....	...	−0.497	−.030	....	...
Oct. 22	+0.341	+.068	−0.529	+.056	+0.189	+.122	−0.767	−.083	−0.469	−.002	−1.421	+.184
Nov. 1	+0.484	+.075	−0.535	+.062	+0.062	−.005	−0.824	−.026	−0.322	+.145	−1.526	+.079
Nov. 4	+0.401	−.008	−0.454	−.019	+0.053	−.014	−0.960	+.110	−0.580	−.113	−1.868	−.263
	+0.409	±.053	−0.473	±.059	+0.067	±.062	−0.850	±.073	−0.467	±.072	−1.605	±.142

For some not very obvious reason, the extinction mean of the three stars varied very much on the four nights. It was respectively (in wedge-readings) 2.051, 2.113, 2.326, and 2.494 inches. It looks very much as if the eye, after practice, became able to follow the star farther before extinction.

For the first three stars the *average* deviation of the determination for each night from the mean of the four nights is ±0.062 in. of the wedge, indicating a *probable* error for one night's work of ±0.054 in., and a probable error of half that amount for the determination by the four nights' observations. Assuming from page 323 that 0.7 in. corresponds to one magnitude, the probable error of the finally determined difference of magnitude between the assumed standard (mean of Nos. 1, 2, and 3) and either of the first three stars is ±0.04 of a magnitude. For star No. 5 (read only five times each night instead of ten), it is about ±0.05 of a magnitude; the *single-night* error is about the same for No. 4, but having been observed only on three nights the final error is correspondingly larger, — about ±0.06 m. The probable error for No. 6 is nearly twice as great; it was obviously too faint to admit of a good determination by the apparatus used.

Measurements of the Transmission of the Pritchard Wedge.

By S. P. LANGLEY.

The recent discussions concerning the use of the Pritchard wedge may give interest to the following description of a study of it made at the suggestion of Professor E. C. Pickering, at Allegheny, by means of the bolometer, in July, 1886.

The wedge experimented upon is graduated from 0 to 6.6 inches, and we selected for measurements of absorption the points 0.3, 1.8, 3.3 (middle), 4.8, and 6.3 inches It is obvious that the increments of the thickness between these points are equal. The measurements are made by sending a horizontal beam from the siderostat through the position occupied by the wedge, w (Figs. 2 and 3), immediately behind which is a micrometer slit, s (whose length is usually kept slightly less than the height of the wedge), with doubly moving jaws set to two millimeters' aperture, the direct beam first being allowed to pass through the slit before the wedge is put in place ("*no wedge*"), and then the wedge being introduced and slid successively into the positions 0.3, 1.8, 3.3, etc.

As all the measures are taken by means of the bolometer, it will be well to precede them by some examples of the degree of accuracy obtainable by it. The probable error of a *single* measurement by the bolometer on any constant source of moderate radiant heat is but a fraction of one per cent.

An absolutely constant source is unattainable, but we give as an illustration ten consecutive readings made in connection with the following experiments, and with the same bolometer (No. 1), on a slowly-cooling Leslie cube. The unit of deflection is a millimeter on the cylindrical scale of the galvanometer.*

DEFLECTION.

(Source of Heat, Leslie Cube.)

	356
	355
	354
	355
	355
	354
	354
	353
	353
	352
Mean	354.1 ± 0.3

* This part of the apparatus is more particularly described in an article "On hitherto Unmeasured Wave-Lengths," in the American Journal of Science for August, 1886.

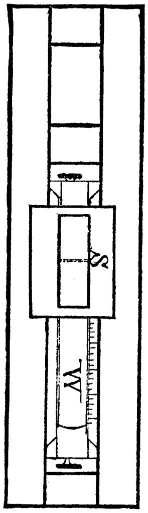

FIG. 2.

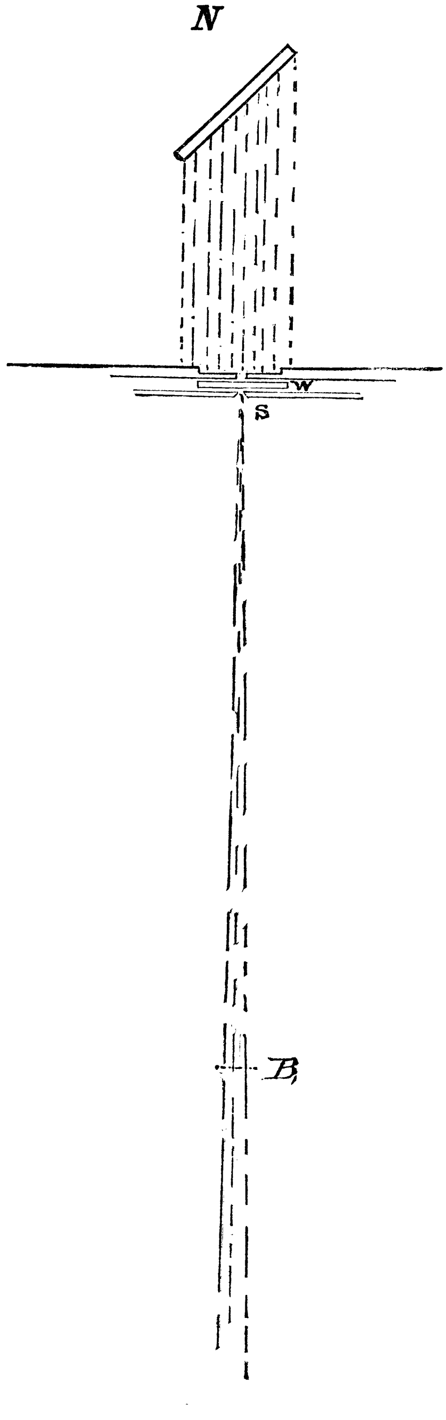

FIG. 3.

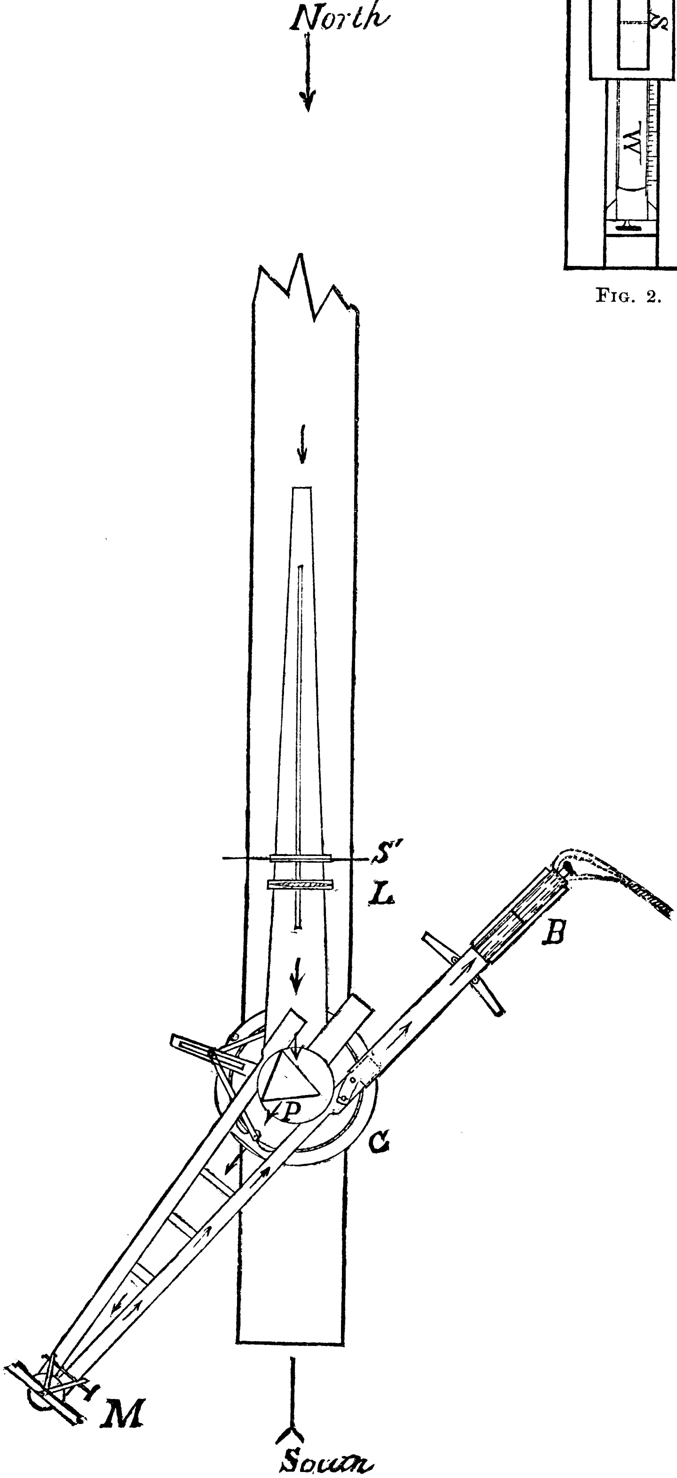

FIG. 4.

Here the probable error of the mean is $\frac{3}{10}$ of one division, or rather less than $\frac{1}{10}$ of one per cent of the whole. The probable error of a single observation is about $\frac{8}{10}$ of one division, or rather less than $\frac{1}{4}$ of one per cent of the whole. Even in this case, however, the probable error is compounded of that due to the instrument and that due to the changing temperature of the source.

If, however, we measure the solar heat, the result is less favorable; for, as I have elsewhere remarked, there is *always* found an incessant fluctuation of the heat transmission from minute to minute under an optically clear sky, or, in other words, the bolometer constantly perceives haze and mist which the eye does not.

The same day on which the above Leslie cube readings were taken, presented to the eye a fair, blue sky, with some cumulous clouds. Except for the passage of a cloud between the ninth and tenth reading, in the following series of twenty readings there was no interruption. The sky was watched critically, and even to a practised eye it appeared as clear at one time as at another. The conditions are the same, except that a shunt was introduced in the solar observations, so that the image should not be sent off the scale by the greater heat.

DEFLECTION.

(SOURCE OF HEAT, SUN, IN OPTICALLY CLEAR SKY.)

	Time 11 h.
	434
	440
	455
	468
	464
	468
	479
	475
	476
Cloud	. . . .
	421
	407
	471
	474
	447
	456
	468
	468
	475
	441
	449
Mean	456.8 ± 3.1

Here the probable error of the mean is 3.1 div., but that of a *single* observation is 13.9 div., or three per cent of the whole. This increased error is due almost wholly to the incessant variations of diathermancy of the air, and, as it will be seen by what has preceded, it is at least twelve times the proper instrumental error. With the aid of the foregoing observations, the reader will have a clearer apprehension of the trustworthiness of the means used in the following determinations.

Two kinds of measure are taken. The first is of the transmission of the total solar radiation; and in this a bolometer of 1 mm. aperture is placed directly in the path of the beam at 5 meters from the slit.

In the second, which is for the purpose of studying the absorption spectrum of the wedge, the beam after passing through the wedge and slit is rendered parallel by a horizontal collimator, L (Fig. 4), of 7.5 meters' focus, whence the rays fall on a large flint prism, P, to form a heat spectrum, which is received by a concave mirror, M, of 1.5 meters' focal length, and focused on the 1 mm. bolometer B, which is now attached to the bolometer spectroscope. The light from the siderostat mirror N is kept accurately adjusted at the centre of the screen S′ placed before the lens L. The deviations correspond to the wave-lengths $0^{\mu}.4$, $0^{\mu}.5$, $0^{\mu}.6$, $0^{\mu}.7$, and $1^{\mu}.0$, the last being invisible.* Whichever kind of measure we take, it is plain that we are in effect working through four successive equal increments of the glass from $0^{\mu}.3$ to $6^{\mu}.6$, and we may as a matter of convenience call each of these increments unity.

In the prismatic observations a difficulty arises from the great range. The scale of the galvanometer is divided into 1,000 equal parts, of which the central 500 are alone ordinarily used; but the range here, from the small heat in the violet ray ($0^{\mu}.4$), passing through the thickest part of the wedge, to the great heat in the red ray ($0^{\mu}.7$), passing through the thinnest part of it, is much over 10,000 to 1. Such differences, it will be understood, only present themselves in the prismatic investigation; but on account of them we have been obliged here to narrow the slit in some cases for the full beam to one half its normal aperture, and to reduce the values thus obtained to what they would have been with the 2 mm. slit usually employed. The values thus obtained are overscored thus: $\overline{100}$.

* μ = 0.001 mm. = 10,000 of Angstrom's scale.

Observations.

We begin by the first kind of observations, — those made in the path of the direct beam, — by measuring the transmission of the total beam at the five points mentioned, going through the wedge from thin end to thick, and then repeating the observation from thick end to thin, so as to eliminate the effect of any progressive change which may be taking place simultaneously outside in the atmospheric absorption. A set of two measures on each point constitutes a series. Each series is complete in itself, and hence (in this first class of observation) it is immaterial if, owing to changes in the sky, the absolute deflections in two series differ.

Nine such series are here given, obtained on two days of excellent sky.

TABLE I.

Time 10 a.m. to 12.20 p.m.

	No Wedge.	Wedge at 0.3 in.	Wedge at 1.8 in.	Wedge at 3.3 in.	Wedge at 4.8 in.	Wedge at 6.3 in.	
⟶	669	296	133	76.7	53.2	38.8	Series 1
⟵	680	294	138	78.3	51.7	38.0	
⟶	678	292	148	82.1	53.4	38.2	Series 2
⟵	666	298	139	82.0	55.5	38.8	
⟶	674	288	136	78.4	52.2	37.2	Series 3
⟵	613	267	131	76.9	51.6	38.5	
⟶	659	282	135	79.0	50.9	37.1	Series 4
⟵	651	284	136	76.8	50.0	38.6	
Mean (a)	661 ± 5.1	288 ± 2.5	137 ± 1.2	78.8 ± 0.5	52.3 ± 0.4	38.2 ± 0.2	
(b)	1000	435.0	207.3	119.2	79.1	57.8	
(c)	. . .	. . .	0.477	0.576	0.664	0.731	

(a) are the actual mean deflections observed on the galvanometer, in units of one millimeter.

(b) are the corresponding proportional value of the original beam.

(c) are quotients obtained by dividing the number in (b), giving absorption at each thickness of the wedge, by the preceding, thus: $\frac{207.3}{435.0} = \frac{477}{1000}$, $\frac{119.2}{207.3} = \frac{576}{1000}$, etc.

Extract from Original Record.

Station, Allegheny.
Date, August 2, 1886.
Temperature of Apparatus = 24° C. at 10 a.m.
State of Sky, Good blue with a very few patches of cirrocumulus. Cumuli forming toward noon.
Aperture of Slit = 2 mm. (Slit 11 mm. high.)

Slit to Bolometer = 5 m.
Galvanometer, No. 3 (damping magnet at 70 cm.).
Time of a single Vibration, 14 seconds.
Bolometer, No. 16 (1 mm. aperture).
Current of Battery = 0.039 Ampère.
Reader at Wedge, J. P.
" *Galvanometer*, F. W. V.
Watcher for Clouds, C.
Object = measurement of transmission of Pritchard wedge for total solar beam.

If there is no selective absorption, those numbers in the line (*b*) which express the absorption for thicknesses of the wedge differing by equal increments should be in geometrical progression, and the numbers in the line (*c*) should represent the constant common ratio. These last, on the contrary, increase progressively and systematically, and the same evidence of selective absorption is derived from those on the following day, August 3, 1886, when they were continued. The only conditions which had changed were:

Temperature of Apparatus, 20°.2 C. at 10.45 A.M.
State of Sky, excellent blue with occasional cumuli.
Time = 9.20 to 10.40 A.M.

TABLE II.

TIME = 9.20 TO 10.40 A.M.

No. Wedge.	Wedge at 0.3 in.	Wedge at 0.8 in.	Wedge at 3.3 in.	Wedge at 4.8 in.	Wedge at 6.3 in.	
758	336	154	82.6	55.4	39.8	Series 1
761	322	145	82.3	54.6	40.3	
757	304	140	77.2	53.4	39.0	Series 2
747	308	141	82.2	53.0	39.5	
761	311	147	82.3	56.7	41.7	Series 3
765	319	148	84.8	56.9	41.2	
763	326	149	85.2	57.7	41.9	Series 4
739	323	148	86.5	57.8	41.2	
744	328	148	85.4	56.3	42.2	Series 5
767	325	151	85.4	57.0	41.8	
Mean (*a*) 756 ± 2	320 ± 2	147 ± 1	83.4 ± 5	55.9 ± 0.4	40.9 ± 0.2	
(*b*) 1000	423.4	194.5	110.3	73.9	54.1	
(*c*) . . .	. . .	0.459	0.567	0.670	0.732	

It is obvious from a comparison of the numbers (*c*) in this table with those in Table I. that there is a very close agreement between the results of the two days, and that the variations in the transmissibility for a unit thickness are dependent on the numbers of unit thickness observed which are systematic and not accidental. To make this fact still more evident, we add in Table II *a.* the results of the nine preceding series, reduced to a uniform quantity of heat, that is, with the varied atmospheric absorption, etc. between the series eliminated.

TABLE II *a.*

No Wedge.	Wedge at 0.3 in.	Wedge at 1.8 in.	Wedge at 3.3 in.	Wedge at 4.8 in.	Wedge at 6.3 in.
1000	437.4	200.9	114.9	77.8	56.9
1000	439.0	213.5	122.2	81.1	57.3
1000	431.3	207.5	120.7	80.7	58.9
1000	432.1	206.9	118.9	77.1	57.9
1000	433.2	196.8	108.6	72.4	52.8
1000	406.9	186.8	106.0	70.7	52.3
1000	412.8	193.3	109.6	74.4	54.4
1000	432.1	197.7	114.4	77.0	55.4
1000	432.2	197.9	113.1	75.1	55.6
Means 1000	428.6 ± 2.5	200.1 ± 1.9	114.3 ± 1.3	76.3 ± 0.8	55.7 ± 0.5

The above are the measurements of transmission of the total solar beam by the Pritchard wedge, each series being reduced separately.

Taking the mean of all the observations in Tables I. and II., we have for the final values:

No Wedge.	Wedge at 0.3 in.	Wedge at 1.8 in.	Wedge at 3.3 in.	Wedge at 4.8 in.	Wedge at 6.3 in.
(*a*) 714	305.7	142.6	81.4	54.3	39.7
(*b*) 1000	428.2	199.7	114.0	76.1	55.6
(*c*) . . .	. . .	0.467	0.570	0.668	0.731

It will be observed that the probable errors above given represent, not only those peculiar to the apparatus, but, what is much more important, the effect of all changes in the sky during some hours' observation. If each series were separately reduced to the form (*b*), the probable error of the mean would be much less.

It is of course admitted that if through any unit stratum of a homogeneous absorbent solid there pass a homogeneous ray of which n parts are transmitted, through the second equal stratum n^2 parts will be transmitted, and through n such

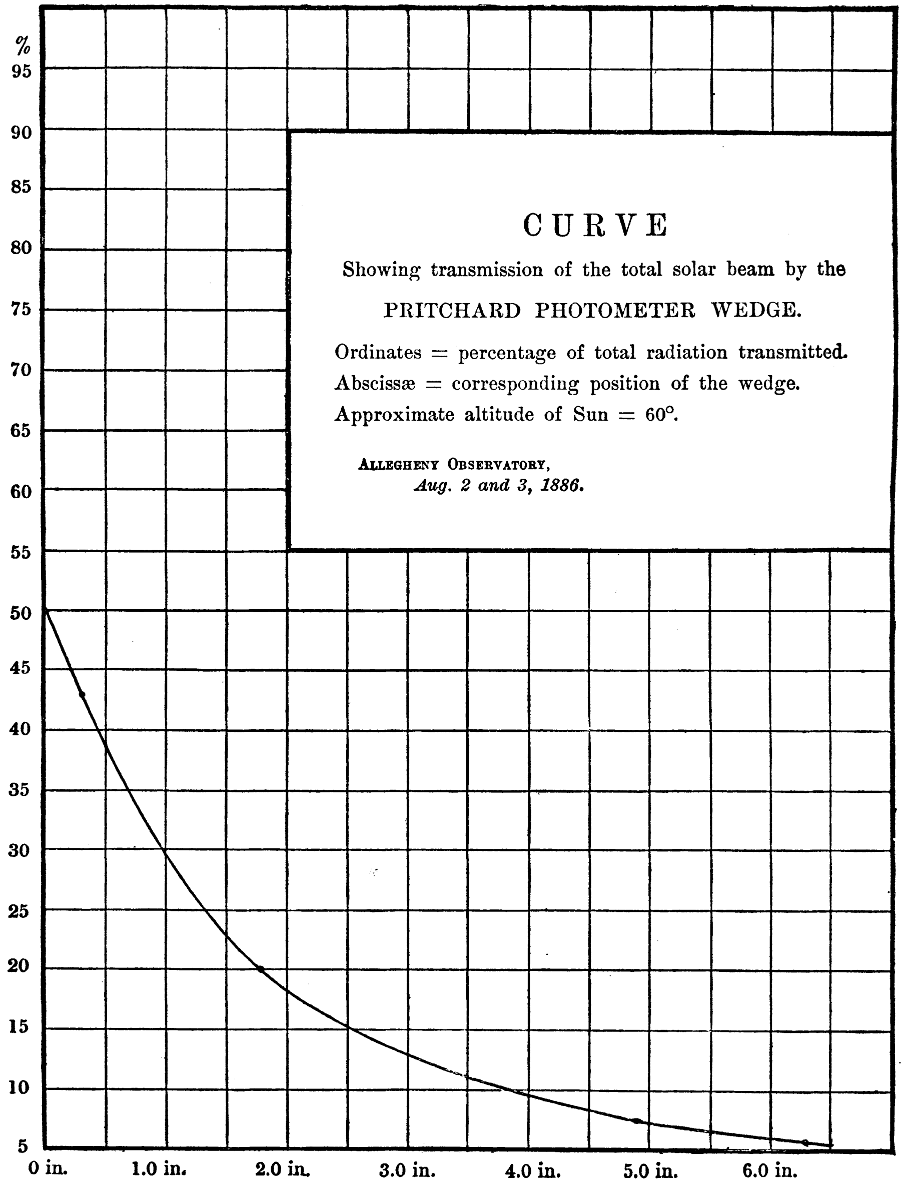

FIG. 5.

strata n^n parts, and that the same result will follow with any ray if there be not selective absorption.

As the result of these measures, we have then, we repeat, both in the tables for each day and in the final values, numbers in a and b which should—if the wedge be

of uniform substance and figure, and apart from the consideration of reflection, etc.— increase in geometrical progression for equal increments of thickness, if there is no selective absorption in the wedge. That this is not so, is shown in *c*, where we find on the contrary that there is a very strongly marked progressive increase in the quotients there given. The variations of *b* are shown graphically in Fig. 5.

A yet more striking proof of the great selective absorption at least of the total *heat* is shown otherwise in line *b*, where we see that the heat transmitted through the thickest part of the wedge is hardly over $\frac{1}{20}$ that of the direct beam. We consider this in connection with the fact that the *light* here transmitted has been found by Professor Pickering to be something like $\frac{1}{1000}$ of the direct light. But though this is evidence of great selective absorption of heat, taking all kinds indiscriminately, it may still be quite possible that this absorption exists chiefly in the invisible, lower part of the spectrum, — that is, in the infra-red, — and that the wedge is sensibly non-selective in the visible part.

To determine this distinct absorption in the visible part, we have the prismatic measures, of which there are four or five incomplete series, obtained on three different occasions. To each of these we have also added a set of measures just *below* the visible part (at 1^{μ}) to make the tendency more evident.*

EXTRACT FROM ORIGINAL RECORD.

Station, Allegheny.
Date, July 27, 1886.
Temperature of Apparatus = 26° C.
State of Sky, milky blue.
Aperture of Slit = 2 mm. (Height of wedge was but 0.59, that of slit used to-day, but no heat entered in any case except through wedge save when that was away altogether. Deflections with wedge away are reduced by multiplying by the factor 0.59.)
Prism used, Hilger No. 3. (A very large Flint prism.)
Spectrum thrown west.
Galvanometer, No. 3.
Time of single Vibration, 9 sec.
Bolometer, No. 16 (1 mm. aperture).

* It may possibly not be superfluous to recall to the reader, that, while the wave-length $0^{\mu}.4$ in the following tables corresponds nearly to the extreme violet, that at $0^{\mu}.7$ to the extreme red, and the visible spectrum or "light heat" lies almost wholly between these points, the greater part of the whole solar energy is found in wave-lengths greater than $0^{\mu}.7$ in the form of *invisible* radiation or "dark heat." (The radiation in wave-lengths beyond the violet is here quite negligible.) As we are not particularly concerned here with this "dark heat," we have confined our measures to points between 0.4 and 0.7 inclusive (light heat), except one set at 1^{μ} (dark heat), just below the red, which we have added to make more evident the tendency of the absorption to *increase* as the wave-lengths increase, though for one and the same unit thickness. If there be any linear selective absorption in the wedge, it is not evident in such observations as these. Of course throughout this investigation the assent of the reader is assumed to the recognized principle that a change in the rate of absorption of the heat in any ray implies a like change in the rate of absorption of light in the same ray.

Setting on Slit (before mounting prism) 0° 0′ 0″.
" D_2* (after " ") 315° 47′ 30″.
Current of Battery = 0.040 Ampère.
Reader (alternately) *at Circle and Wedge*, J. P.
" *at Galvanometer*, F. W. V.
Object = measurement of transmission of Pritchard wedge for different parts of the spectrum.
Time 11.30 A.M. to 2.05 P.M.

TABLE III.

λ	No Wedge.	Wedge at 0.3 in.	Wedge at 1.8 in.	Wedge at 3.3 in.	Wedge at 4 8 in.	Wedge at 6.3 in.
⟶ 0µ.4	$\overline{40.7}$	9.1	1.5	. . .	. . .	. . .
⟵ (Dev. 46° 40′)	$\overline{35.7}$	9.5	1.3	. . .	. . .	. . .
Mean of Series 1	$\overline{38.2}$	9.3	1.4	. . .	. . .	. . .
⟶ 0µ.5	$\overline{174.0}$	47.5	7.4	1.2	. . .	. . .
⟵ (Dev. 44° 58′)	$\overline{174.0}$	50.5	7.1	1.1	. . .	. . .
Mean of Series 2	$\overline{174.0}$	49.0	7.3	1.2	. . .	. . .
⟶ 0µ.6	$\overline{347.0}$	99.0	12.9	3.3	0.7	. . .
⟵ (Dev. 44° 7′)	$\overline{338.0}$	100.0	14.4	2.3	0.4	. . .
Mean of Series 3	$\overline{343.0}$	99.5	13.7	2.8	0.6	. . .
⟶ 0µ.7	$\overline{520.0}$	225.0	61.4	17.3	5.3	1.1
⟵ (Dev. 43° 37′)	$\overline{533.0}$	261.0	68.0	16.0	4.9	0.7
Mean of Series 4	$\overline{527.0}$	243.0	64.7	16.7	5.1	0.9
⟶ 1µ.0	$\overline{822.0}$	504.0	267.0	137.0	65.0	34.2
⟵ (Dev. 42° 54′)	$\overline{835.0}$	454.0	213.0	122.0	62.0	35.0
Mean of Series 5	$\overline{829.0}$	479.0	240.0	129.0	63.5	34.6

PRISMATIC OBSERVATIONS OF WEDGE TRANSMISSION OF AUGUST 9, 1886.

EXTRACT FROM ORIGINAL RECORD.

Temperature of Apparatus = 25°.3 C. at 11 A.M.
State of Sky, milky blue with cumuli.
Aperture of Slit = 2 mm. (Height of slit is to-day reduced to 11 mm., or slightly *less* than that of the wedge.)
Prism used, Hilger No. 3.
Galvanometer, No. 3 (damping magnet at 70 cm.).
Time of a single Vibration = 14 seconds.

* An optical setting on the sodium line D_2 is always made as a check on the accuracy of adjustment of the prismatic apparatus.

Bolometer, No. 16 (1 mm. aperture), accurately adjusted for the varying focus of each point in the spectrum.
Setting on Slit (before mounting prism) = 0° 0′ 0″.
" D_2 (after " ") = 315° 48′ 15″.
Current of Battery, 0.040 Ampère.
Reader at Circle and Wedge, J. P.
" *Galvanometer*, F. W. V.
Watcher for Clouds, C.
Object = measurement of transmission of Pritchard wedge for different parts of the spectrum.
Time, 11 A.M. to 2.15 P.M.

TABLE IV.

λ	No Wedge.	Wedge at 0.3 in.	Wedge at 1.8 in.	Wedge at 3.3 in.	Wedge at 4.8 in.	Wedge at 6.3 in.
⟶ $0^{\mu}.4$	52.0	12.7	1.9	. . .	. . .	. . .
⟵ (Dev. 46° 40′)	56.1	13.3	1.1	. . .	. . .	. . .
Mean of Series 1	54.1	13.0	1.5	. . .	. . .	. . .
⟶ $0^{\mu}.5$	267.0	68.4	9.0	1.4	. . .	. . .
⟵ Dev. (44° 58′)	244.0	65.9	9.7	1.1	. . .	. . .
Mean of Series 2	256.0	67.2	9.4	1.3	. . .	. . .
⟶ $0^{\mu}.6$	566.0	157.0	21.2	3.2	0.4	. . .
⟵ (Dev. 44° 7′)	588.0	158.0	19.4	2.4	0.2	. . .
Mean of Series 3	577.0	158.0	20.3	2.8	0.3	. . .
⟶ $0^{\mu}.7$	$\overline{799.0}$	311.0	83.5	21.5	5.1	1.0
⟵ (Dev. 43° 37′)	$\overline{733.0}$	319.0	88.0	21.8	5.1	1.4
Mean of Series 4	$\overline{766.0}$	315.0	85.8	21.7	5.1	1.2
⟶ $1^{\mu}.0$	$\overline{933.0}$	578.0	311.0	152.0	83.0	37.9
⟵ (Dev. 42° 54′)	$\overline{1014.0}$	581.0	288.0	158.0	80.5	34.9
Mean of Series 5	$\overline{974.0}$	580.0	300.0	155.0	81.8	36.4
⟶ $0^{\mu}.4$	42.9	8.6	1.5	. . .	. . .	. . .
⟵ (Dev. 46° 40′)	42.6	9.8	1.1	. . .	. . .	. . .
Mean of Series 6	42.8	9.2	1.3	. . .	. . .	. . .
$0^{\mu}.5$, $0^{\mu}.6$ } Clouds prevented the completion of these series.						
⟶ $0^{\mu}.7$	$\overline{756.0}$	299.0	78.5	19.8	5.1	1.1
⟵ (Dev. 43° 37′)	$\overline{721.0}$	286.0	79.0	21.7	5.9	1.1
Mean of Series 7	$\overline{740.0}$	293.0	78.8	20.8	5.5	1.1
⟶ $1^{\mu}.0$	$\overline{948.0}$	468.0	260.0	143.0	78.8	31.9
⟵ (Dev. 42° 54′)	$\overline{896.0}$	572.0	282.0	150.0	85.5	37.2
Mean of Series 8	$\overline{923.0}$	520.0	271.0	147.0	82.2	34.6

PRISMATIC OBSERVATIONS OF WEDGE TRANSMISSION MADE AUGUST 10, 1886.

TABLE V.

λ	No Wedge.	Wedge at 0.3 in.	Wedge at 1.8 in.	Wedge at 3.3 in.	Wedge at 4.8 in.	Wedge at 6.3 in.
⟶ $0^{\mu}.4$	35.3	10.0	1.0	. . .	. . .	. . .
⟵ (Dev. 46° 40′)	37.0	8.6	1.4	. . .	. . .	. . .
Mean of Series 1	36.2	9.3	1.2	. . .	. . .	. . .
⟶ $0^{\mu}.5$	173.0	64.5	9.2	1.3	. . .	. . .
⟵ (Dev. 44° 58′)	245.0	70.1	11.2	0.6	. . .	. . .
Mean of Series 2	209.0	67.3	10.2	1.0	. . .	. . .
⟶ $0^{\mu}.6$	482.0	132.0	19.7	2.6	. . .	. . .
⟵ (Dev. 44° 7′)	566.0	125.0	16.7	2.6	. . .	. . .
Mean of Series 3	524.0	129.0	18.2	2.6	. . .	. . .
⟶ $0^{\mu}.7$	$\overline{810.0}$	308.0	86.3	21.7	6.4	1.7
⟵ (Dev. 43° 37′)	$\overline{865.0}$	330.0	90.6	23.1	6.6	1.6
Mean of Series 4	$\overline{838.0}$	319.0	88.5	22.4	6.5	1.6
⟶ $1^{\mu}.0$	$\overline{1240.0}$	684.0	367.0	190.0	96.2	51.4
⟵ (Dev. 42° 54′)	$\overline{1176.0}$	692.0	369.0	197.0	95.7	49.9
Mean of Series 5	$\overline{1209.0}$	688.0	368.0	194.0	96.0	50.7
Above observations taken before 12.30 P.M.; the following, after 12.30 P.M.						
⟶ $0^{\mu}.4$	30.9	7.2	0.6	. . .	. . .	. . .
⟵ (Dev. 46° 40′)	35.9	7.8	0.6	. . .	. . .	. . .
Mean of Series 6	33.4	7.5	0.6	. . .	. . .	. . .
⟶ $0^{\mu}.5$	191.0	52.6	6.3	0.9	. . .	. . .
⟵ (Dev. 44° 58′)	208.0	55.0	7.5	1.1	. . .	. . .
Mean of Series 7	200.0	53.8	6.9	1.0	. . .	. . .
⟶ $0^{\mu}.6$	430.0	122.0	17.9	2.3	. . .	. . .
⟵ (Dev. 44° 7′)	497.0	134.0	16.5	2.7	. . .	. . .
Mean of Series 8	464.0	128.0	17.2	2.5	. . .	. . .
⟶ $0^{\mu}.7$	$\overline{742.0}$	275.0	76.6	19.6	5.0	0.9
⟵ (Dev. 43° 37′)	$\overline{762.0}$	279.0	76.2	19.4	5.1	1.1
Mean of Series 9	$\overline{752.0}$	277.0	76.4	19.5	5.1	1.0
⟶ $1^{\mu}.0$	$\overline{1129.0}$	671.0	345.0	184.0	98.6	43.8
⟵ (Dev. 42° 54′)	$\overline{1121.0}$	682.0	353.0	187.0	95.6	44.5
Mean of Series 10	$\overline{1124.0}$	677.0	349.0	186.0	97.1	44.2

EXTRACT FROM ORIGINAL RECORD.

Conditions the same as on the previous day, August 9, except the following:—
Temperature of Apparatus = 30 C. at 2 P.M.
State of Sky, milky blue with cumuli. Good sky between clouds.
Setting on D_2 = 315° 47′ 15″. (Slit = 0° 0′ 0″.)
Battery Current = 0.038 Ampère.
Object = repetition of measurements of wedge transmission at different points in the spectrum.
Time of first five series 10.15 A.M. to 12.30 P.M.
" last " " 12.30 P.M. to 1.45 P.M.

In our measures in the direct beam each series was complete in itself, and hence we were independent of any changes of the weather from day to day; but here, though the series as between different points of the wedge may be also complete in itself, it is not necessarily true that the comparison between different wave-lengths made on different days, though at the same point of the wedge, is to be made with equal immunity.

Owing to variations in the initial solar radiation, due to atmospheric changes and the alteration of atmospheric absorption, with the changing altitude of the sun, the foregoing series as represented by the *vertical* columns are not then so strictly comparable with each other; nor, rigorously speaking, can one day be exactly comparable with another when the progressive absorption in the spectrum is in question, rather than the rate of absorption for different parts of the wedge. The following continuous series, made when the sun's altitude above the horizon was 54°, with the wedge set at 0.3 in., will however serve to indicate the relative intensities for one position.

TABLE VI.

WEDGE AT 0.3 in.

Wave-Length (λ).	$0^\mu.4$	$0^\mu.5$	$0^\mu.6$	$0^\mu.7$	$1^\mu.0$
⟶	7.2	48.6	104.0	246.0	553.0
⟵	5.9	44.0	95.4	250.0	561.0
Mean Deflections	6.6	46.3	99.7	248.0	557.0

There is of course no reason why similar series should not be taken for every part of the wedge, except the inordinate time demanded in waiting for days of unexceptionable clearness; for experience seems to show that with all its drawbacks sunlight is better for this purpose than artificial light.

In order to summarize the results of the prismatic measures in Tables III., IV., and V., all the observations taken on the same successive points of the wedge, though on different days, have been grouped together in Tables VII., VIII., IX., X., and XI. The numbers in each horizontal line have been divided in turn by the first number in the line, viz. that for "*no wedge.*" Thus in Table III., $\frac{9.1}{40.7} = 224$, $\frac{47.5}{174} = 273$, the numbers which begin the horizontal line opposite "July 27" in Table VII. below.

TABLE VII.

WEDGE AT 0.3 in. SLIT = 2 mm.

λ =	$0^{\mu}.4$	$0^{\mu}.5$	$0^{\mu}.6$	$0^{\mu}.7$	$1^{\mu}.0$
July 27	224	273	286	433	613
" 27	266	289	296	490	544
August 9	244	256	277	389	620
" 9	237	270	269	435	573
" 9	200	. . .	. . .	396	494
" 9	231	. . .	. . .	397	638
August 10	283	373	274	380	552
" 10	232	286	221	382	588
" 10	233	275	284	371	594
" 10	217	264	271	366	609
Means	217 ± 5	286 ± 7	272 ± 5	404 ± 8	583 ± 9

TABLE VIII.

WEDGE AT 1.8 in. SLIT = 2 mm.

λ	$0^{\mu}.4$	$0^{\mu}.5$	$0^{\mu}.6$	$0^{\mu}.7$	$1^{\mu}.0$
July 27	37	43	37.2	118	325
" 27	36	41	42.6	128	255
August 9	37	34	37.5	105	333
" 9	20	40	33.0	120	284
" 9	35	. . .	. . .	104	274
" 9	27	. . .	. . .	110	315
August 10	28	53	40.9	107	296
" 10	36	46	29.5	105	314
" 10	18	33	41.6	103	305
" 10	17	36	33.2	100	315
Means	29.1 ± 2.0	40.8 ± 1.6	36.9 ± 1.2	110 ± 2.0	302 ± 5.0

TABLE IX.

WEDGE AT 3.3 in. SLIT = 2 mm.

λ =	$0^{\mu}.4$	$0^{\mu}.5$	$0^{\mu}.6$	$0^{\mu}.7$	$1^{\mu}.0$
July 27	. . .	6.9	9.5	33.3	167
" 27	. . .	6.3	6.8	30.0	146
August 9	. . .	5.3	5.6	26.9	163
" 9	. . .	4.5	4.0	29.7	156
" 9	. . .	. . .	. . .	26.2	151
" 9	. . .	. . .	. . .	30.1	167
August 10	. . .	7.5	5.4	26.8	153
" 10	. . .	2.4	4.6	26.7	168
" 10	. . .	4.7	5.2	26.4	163
" 10	. . .	5.1	5.4	25.5	167
Means	. . .	5.3 ± 0.4	5.8 ± 0.4	28.2 ± 0.8	160 ± 2.0

TABLE X.

WEDGE AT 4.8 in. SLIT = 2 mm.

λ =	$0^{\mu}.4$	$0^{\mu}.5$	0 .6	$0^{\mu}.7$	$1^{\mu}.0$
July 27	. . .	. . .	2.0	10.2	79.1
" 27	. . .	. . .	1.2	9.2	74.3
August 9	. . .	. . .	1.2	6.4	89.0
" 9	. . .	. . .	0.6	7.0	79.4
" 9	. . .	. . .	. .	6.7	83.1
" 9	. . .	. . .	. . .	8.2	95.4
August 10	. . .	. . .	. . .	7.9	77.6
" 10	. . .	. . .	. . .	7.6	81.4
" 10	. . .	. . .	. . .	6.7	87.3
" 10	. . .	. . .	. . .	6.7	85.4
Means	. . .	. . .	1.3 ± 0.2	7.7 ± 0.3	83.2 ± 1.4

It is not to be understood from Table XI. and others, that no sensible heat of the shorter wave-lengths is transmitted through the thicker parts of the wedge. We do not here cite such observations where any have been made, because for greater security no conclusions have been founded on the minute amounts there noted, which are liable to relatively large errors of observation.

TABLE XI.

WEDGE AT 6.3 in. SLIT = 2 mm.

$\lambda =$	$0^{\mu}.4$	$0^{\mu}.5$	$0^{\mu}.6$	$0^{\mu}.7$	$1^{\mu}.0$
July 27	. . .	. . .	. . .	2.1	41.6
" 27	. . .	. . .	. . .	1.3	41.9
August 9	. . .	. . .	. . .	1.3	40.6
" 9	. . .	. . .	. . .	1.8	34.4
" 9	. . .	. . .	. . .	1.5	33.7
" 9	. . .	. . .	. . .	1.5	41.5
August 10	. . .	. . .	. . .	2.1	41.5
" 10	. . .	. . .	. . .	1.8	42.4
" 10	. . .	. . .	. . .	1.2	38.8
" 10	. . .	. . .	. . .	1.4	39.7
Means	. . .	. . .	. . .	1.6 ± 0.1	39.6 ± 0.7

TABLE XII.

SUMMARY OF TRANSMISSION BY PRITCHARD WEDGE FOR DIFFERENT WAVE-LENGTHS.

λ		No Wedge.	Wedge 0.3 in.	Ratio.	Wedge 1.8 in.	Ratio.	Wedge 3.3 in.	Ratio.	Wedge 4.8 in.	Ratio.	Wedge 6.3 in.
$0^{\mu}.4$	(*b*)	1000	237		29.1						
	(*c*)			0.123							
0.5	(*b*)	1000	286		40.8		5.3				
	(*c*)			0.143		0.130					
0.6	(*b*)	1000	272		36.9		5.8		1.3		
	(*c*)			0.136		0.157		0.224			
0.7	(*b*)	1000	404		110.0		28.2		7.7		1.6
	(*c*)			0.272		0.256		0.273		0.208	
1.0	(*b*)	1000	583		302.0		160.0		83.2		39.6
	(*c*)			0.518		0.530		0.520		0.476	

For $\lambda =$	$0^{\mu}.4$	$0^{\mu}.5$	$0^{\mu}.6$	$0^{\mu}.7$	$1^{\mu}.0$
Mean Value of (*c*) =	0.123	0.137	0.172	0.252	0.511

(c) may be considered in the case of a *homogeneous* ray as the *constant of transmission* for a unit thickness of the absorbing material. As the writer has elsewhere shown, it is not only *not* a constant for non-homogeneous rays, but for these latter (though still reckoned for a unit thickness) it increases as the thickness from which it is determined increases. These variations are shown in Fig. 6.

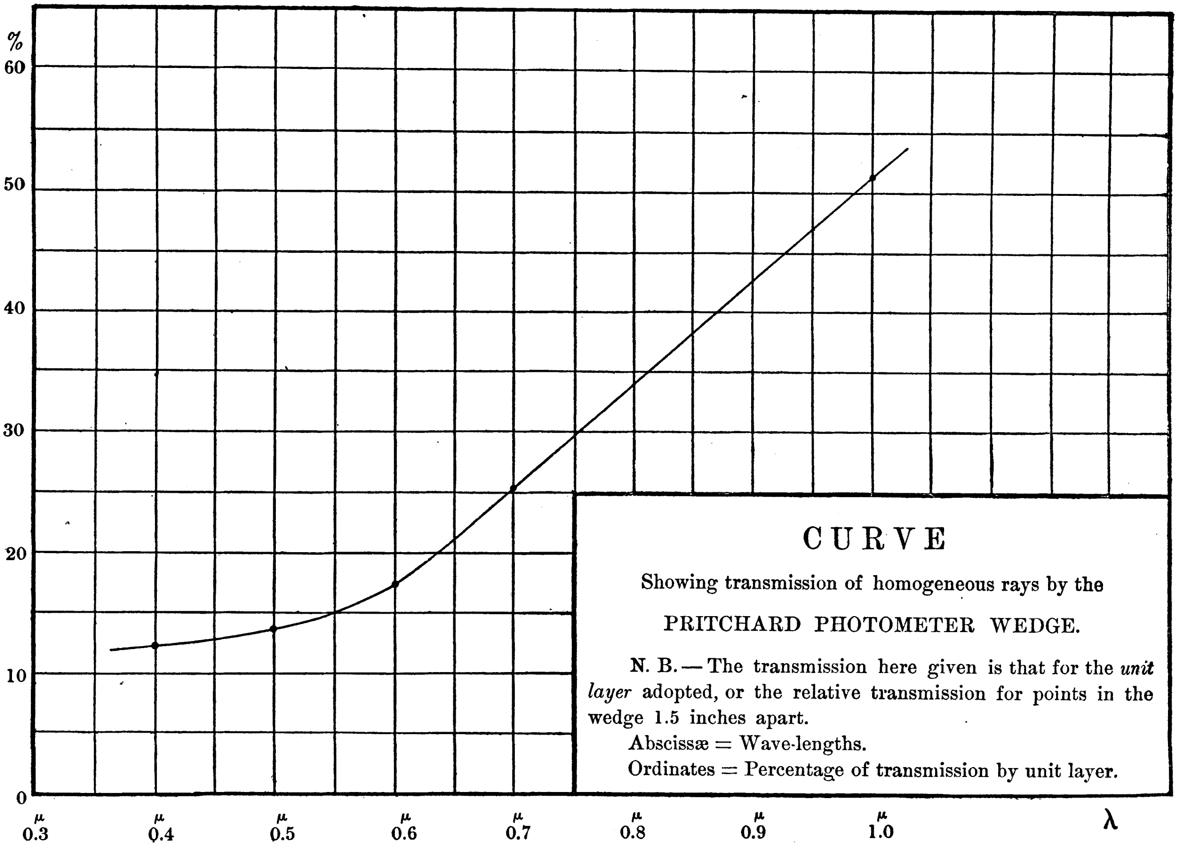

Fig. 6.

In these prismatic measures the light is nearly homogeneous, and here it will be seen, by considering the ratios in the horizontal line corresponding to any single wave-length, that the ratios are constant for each ray, except for the relatively considerable errors of observation where the heat is feeble, and for the variations due to fluctuations in the original solar radiation, which may be large even with the clearest sky; * but as we go from one ray to another the ratios differ, and this difference grows very marked as we approach the red end at $0^{\mu}.7$.

* That the irregularities due to variations in the solar beam itself are relatively very much greater than those proceeding from purely instrumental causes, may also be inferred from the probable errors attached to the mean deflections of Tables I. and II; since, if these probable errors are expressed as percentages of the corresponding deflections, it will be seen that they are but slightly greater for the small deflections than they are for the large ones.

The lower line, "Mean Value of (c)," exhibits in the constant increment an interesting proof of the correctness of a theory elsewhere applied to the results of atmospheric absorption, and these prismatic observations then, on the whole, while extending and elucidating those in the direct beam, are in strict accordance with them.

CONCLUSION.

It appears from all the preceding observations, and from the established principle that changes in the thermal and optical effects are proportional in any one ray, that there is a selective absorption of light throughout the wedge, even in the visible rays; feeble in the more luminous portion of the spectrum, but of such a character that, broadly speaking, the transmissibility always increases from the violet towards the red. That it increases, and very greatly, beyond the red, is shown clearly by the additional measures we have given at $1^{\mu}.0$ in the infra-red spectrum.

Though the eye is incomparably more sensitive than the bolometer, the latter is probably able to discriminate much smaller differences quantitatively. It is therefore possible that the selective absorption so apparent to the bolometer even in the luminous spectrum may not be easily sensible ocularly, particularly as this absorption is seen to be less in the portions which are most effective in vision, such as the yellow, than in the red.

These observations, then, demonstrate that selective absorption of a quite definite character and amount exists in the submitted example of the Pritchard wedge, even in the visible rays; but they are not to be understood as necessarily proving that it does so in any degree very prejudicial to the special object of the instrument.

S. P. LANGLEY,
Director of the Allegheny Observatory.

AUGUST, *1886.*

The unexpected character of the results obtained by Professor Langley, and the importance of the conclusions to be derived from them, render it desirable that they should be checked by some wholly independent method. The wedge to the eye is of a nearly perfect neutral tint, and might be expected to transmit equally rays of all wave-lengths. The bolometer, however, shows that the variation is very great even in the visible spectrum. The proportion transmitted corresponding to a length of $1\frac{1}{2}$ inches, is 0.137 for blue light, $\lambda = 0.5$, and 0.252 for red light, $\lambda = 0.7$. This quantity corresponds to a difference of 0.44 of a magnitude per inch in the

constant of the wedge if used to measure a star emitting rays composed entirely of these wave-lengths. As might be expected, when the invisible rays are included, the effect is still more marked. The portion of the total energy transmitted by the thick end of the wedge, as determined by the bolometer, is fifty times as great as the corresponding fraction of the visible light.

A series of photometric measurements were made of the wedge at the Harvard College Observatory. A photometer was used in which two portions of the same beam of light could be compared by a Nicol and double-image prism. The measures were made after one of these portions had passed through the wedge at a given distance from its end. If we employ the term *absorption* to denote the numerical increase of stellar magnitude effected by the action of the wedge, these observations could be represented by the formula $m = 0.6 + 1.3\,n$, in which m denotes the absorption, and n the reading of the scale corresponding to the part of the wedge employed in the observation. This gives, for the absorption of the point marked zero, 0.6, or the quantity whose logarithm is 0.24. In like manner the absorption for each inch in length is 1.3 magn., corresponding to the logarithm 0.52. This agrees closely with 0.51, the value found by Professor Langley for the yellow ray, $\lambda = 0.6$. The photometric measures described above failed to show the gradual diminution in the coefficient of absorption as the thickness increased. In fact, the deviation appears to be in the opposite direction. Perhaps this is due to light reflected from the rear surface of the glass, or other sources of error. As the light transmitted by the thick end of the wedge is only about one five-thousandth of the total light, a slight error in its measurement would be sufficient to produce this effect.

Another determination of the absorption of the wedge was made by photographing the solar spectrum through it. An exposure of 61 minutes gave a good photograph of the spectrum of the light of the sky when passing through the part of the wedge 3.5 inches from its end. Several exposures of from 5 to 30 seconds were made on the same plate after removing the wedge. From about $\lambda = 0.5$ where the photographic image began, to $\lambda = 0.43$, the spectrum with the wedge had nearly the same intensity as the spectrum without the wedge, having an exposure of 10 seconds. Photographic action appears to be nearly independent of the time during which a given amount of energy is expended upon a plate. In other words, the light required to produce a given image is nearly inversely proportional to the exposure. The logarithm of the proportion of the light transmitted by the wedge would therefore be 7.44. Allowing 0.24 for the absorption of the wedge at the

point marked zero, as found above, we have 7.78 for the reduction caused by 3.5 inches. This gives for the absorption per inch the ratio whose logarithm is 0.7, or a somewhat greater value than that found by Professor Langley. The photograph shows that the intensity of the spectrum transmitted by the wedge falls off rapidly beyond $\lambda = 0.41$, the photographic image becoming entirely invisible where $\lambda = 0.40$. The H and K lines cannot be detected in this spectrum, although readily seen in the other images. The opacity of the wedge increases rapidly as the wave-length diminishes, as shown by the bolometer. A second photograph was taken of the light transmitted at the point marked 5.5 inches, and confirmed the above results. The exposure lasted for nearly an entire day, and the brightest part was about equal to a spectrum obtained in 10 seconds without the wedge. As before, the H and K lines were invisible.

In conclusion, the Uranometria Oxoniensis shows that valuable results may be obtained with the wedge photometer in skilful hands. But the experiments described above show sources of error which must be carefully studied before we can safely apply it to stars of different colors, or to detecting small systematic errors in star catalogues.